Example: Parametric fire curve for a fire compartment

This example shows the determination of the parametric fire curve for a fire compartment in an office building, according to Annex A of EN 1991-1-2. The walls and the floors above and below the compartment are of reinforced concrete; the walls have several openings. Reference is made to SD006 for the thermal properties of the walls and floors.

Basic data

Dimensions of the fire compartment

- Width: \( a = 8.5 \text{ m} \)
- Length: \( b = 10.0 \text{ m} \)
- Height: \( h = 3.15 \text{ m} \)
- Height of opening: \( h_{\text{op}} = 1.537 \text{ m} \)
- Width of opening: \( b_{\text{op}} = 3.85 \text{ m} \)
- Number of openings: \( n = 4 \); see Figure 1.

![Figure 1: Considered fire compartment](image)

The floor and ceiling are made from reinforced concrete

- Density: \( \rho = 2300 \text{ kg m}^{-3} \) \( \text{SD006} \)
- Specific heat: \( c = 840 \text{ J kg}^{-1} \text{ K}^{-1} \)
- Thermal conductivity: \( \lambda = 1.57 \text{ W m}^{-1} \text{ K}^{-1} \)

The walls are made from lightweight concrete

- Density: \( \rho = 500 \text{ kg m}^{-3} \) \( \text{SD006} \)
- Specific heat: \( c = 840 \text{ J kg}^{-1} \text{ K}^{-1} \)
- Thermal conductivity: \( \lambda = 0.22 \text{ W m}^{-1} \text{ K}^{-1} \)
**Fire load density**

For office buildings, the characteristic fire load density related to floor area, for the 80% fractile case (Gumbel distribution) is given by Table E.4 as:

\[ q_{f,k} = 511 \text{ MJ m}^{-2} \]

The floor area is

\[ A_f = a \cdot b = 8,5 \cdot 10,0 = 85 \text{ m}^2 \]

The factor to take into account the fire activation risk due to the size of the compartment is given by linear interpolation from Table E.1:

\[ \delta_{q1} = 1,1 + (1,5 + 1,1) \cdot (85 - 25)/(250 - 25) = 1,20 \]

For the factor to take into account the fire activation risk due to the type of occupancy \( \delta_{q2} = 1,00 \).

The factor to take into account the different fire fighting measures \( \delta_n = 1,00 \).

The design fire load density is given by:

\[ q_{f,d} = q_{f,k} \delta_{q1} \delta_{q2} \delta_n \]

\[ = 511 \cdot 1,20 \cdot 1,00 \cdot 1,00 = 613 \text{ MJ m}^{-2} \]

**Thermal properties of the fire compartment**

The total area of the enclosure is:

\[ A_t = 2 \cdot A_f + 2 \cdot (a + b) \cdot h = 2 \cdot 85 + 2 \cdot (8,5 + 10,0) \cdot 3,15 = 286,55 \text{ m}^2 \]

The total area of vertical openings is:

\[ A_v = n \cdot h_{op} \cdot b_{op} = 4 \cdot 1,537 \cdot 3,85 = 23,67 \text{ m}^2 \]

The surface factor for floor and ceiling is:

\[ b = \sqrt{\rho \cdot c \cdot \lambda} = \sqrt{2300 \cdot 840 \cdot 1,57} = 1742 \text{ J m}^{-2}s^{-0.5}K^{-1} \]

The surface factor for walls is:

\[ b = \sqrt{\rho \cdot c \cdot \lambda} = \sqrt{500 \cdot 840 \cdot 0,22} = 304 \text{ J m}^{-2}s^{-0.5}K^{-1} \]

Both values are within the limit \( 100 \leq b \leq 2200 \).
### Ventilation properties of the fire compartment

The opening factor is:

\[ O = \frac{A_v \cdot \sqrt{h_{eq}}}{A_t} = \frac{23.67 \cdot \sqrt{1.537}}{286.55} = 0.1024 \text{ m}^{0.5} \]

where the weighted average height of the openings \( h_{eq} = 1.537 \text{ m} \).

The opening factor should be within the limits \( 0.02 \leq O \leq 0.2 \text{ [m}^{0.5}] \). The limitation is satisfied.

### Time factor function

The \( \Gamma \) factor is given by:

\[ \Gamma = \left( \frac{O}{b} \right)^2 = \left( \frac{0.1024}{1234} \right)^2 = 5.791 \]

### Fire load density related to surface area

The design fire load density related to the surface area is given by:

\[ q_{t,d} = \frac{q_{f,d} A_t}{A_i} = \frac{613 \cdot 85}{286.55} = 181.8 \text{ MJ m}^{-2} \]
**Evaluation of the limiting time and maximum temperature**

Medium fire growth rate is expected, with $t_{\text{lim}} = 20 \text{ min} = 0.333 \text{ hour}$.

The time $t_{\text{max}}$ to reach the maximum temperature is given by:

$$t_{\text{max}} = \max \left\{ \frac{0.2 \cdot 10^{-3} q_{t,d}}{O}, \frac{0.2 \cdot 10^{-3} \cdot 181.8}{0.1024 + 0.333} \right\} = 0.355 \text{ hour}$$

The fire is ventilation-controlled, because $t_{\text{max}}$ is given by the first term.

The time to reach maximum temperature, taking account of the openings and thermal absorptivity, $t_{\text{max}}^*$ is given by:

$$t_{\text{max}}^* = t_{\text{max}} \Gamma = 0.355 \cdot 5.791 = 2.056 \text{ hour}$$

and the maximum gas temperature is given by:

$$\theta_{\text{max}} = 20 + 1325 \left( 1 - 0.324 e^{-0.2 \cdot 2.056} - 0.204 e^{-1.7 \cdot 2.056} - 0.472 e^{-19 \cdot 2.056} \right) = 1052{\circ}\text{C}$$

**The curve in the heating phase**

The gas temperature in the heating phase is given by

$$\theta_{g,t} = 20 + 1325 \left( 1 - 0.324 e^{-0.2 t^*} - 0.204 e^{-1.7 t^*} - 0.472 e^{-19 t^*} \right)$$

where the time $t^*$ is given by:

$$t^* = t \Gamma = 5.791 t$$

**The curve in the cooling phase**

For $t_{\text{max}}^* > 2$ hours, the gas temperature in the cooling phase is given by:

$$\theta_{g,t} = \theta_{\text{max}} - 250 \left( t^* - t_{\text{max}}^* \right) = 1052 - 250 \cdot (t^* - 2.056 \cdot 1) = 1566 - 250 \cdot t^*$$

where the factor $x = 1$ for a ventilation-controlled fire.

The resulting parametric curve is shown in Figure 2.
**Figure 2: Gas temperature-time curve**
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<tbody>
<tr>
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